POPULATION ESTIMATION AND DEMOGRAPHY OF THE RAJAJI NATIONAL PARK ELEPHANTS, NORTH-WEST INDIA[1]

Amirtharaj C. Williams[2], Asir J.T. Johnsingh[3] and Paul R. Krausman[4]

[1]Accepted March 2006

[2]Present address: c/o WWF-Nepal Program, P.O. Box 7660, Baluwatar, Kathmandu, Nepal. Email: acwill69@yahoo.com
[3]Wildlife Institute of India, P.O. Box 18, Dehradun 248 001, Uttarakhand, India. Email: ajt.johnsingh@gmail.com
[4]Boone and Crockett Professor of Wildlife Conservation, College of Forestry and Conservation, Wildlife Biology Program, 32 Campus Drive, Forestry Building, University of Montana, Missoula, MT 59812. Email: paul.krausman@umontana.edu

The Asian Elephant (*Elephas maximus*) population in Rajaji National Park, north-west India is an important part of India's heritage, but has not been intensively studied until recently. Understanding the population dynamics is important for managers if the population is to remain viable. We used marked adult male Asian Elephants in a mark re-sight method to estimate the male segment of the population and the estimated number of female and associated young using their proportions relative to the adult male segment from classification data. We collected data on inter-calving period and calf survival from adult females present in groups with radio collared females. The number of adult males in the study area was estimated to be 31 (95% CI = 23-41). We computed the relative proportions of other age-sex classes to the adult males and estimated 188 elephants (95% CI = 139-248). Ninety per cent of the adult males had tusks (tuskers) and the adult male to adult female ratio was 1:1.87. This is one of the least skewed sex ratios reported for Asian Elephants and is comparable to areas in Sri Lanka where 95% of males are tuskless. Over 90% of the adult females were accompanied by juveniles or calves <5 years old. We estimated the inter-calving period to be around 4.23 years and the calf survival over the first year was almost 100%. One calf was killed when hit by a train. The high proportion of males, low inter-calving period, and high neonate survival of the Rajaji elephant population indicates that the population is demographically healthy. However, more adult elephants died in train accidents than due to natural causes and viability of this small population could be seriously threatened if losses to train accidents continue.

Key words: Asian Elephant, inter-calving period, radio collared females, Rajaji National Park, population estimation, demography

INTRODUCTION

The Asian Elephant (*Elephas maximus*) is an endangered mammal with an estimated 35,000 to 50,000 elephants occurring in 13 countries across Asia (Kemf and Santiapillai 2000). They are long-lived animals that reproduce slowly and live in forested habitats; observations in the wild are difficult to obtain. Therefore, demographic status is uncertain for many Asian Elephant populations. Estimates of population numbers or densities are some of the basic information required to formulate proper management and conservation strategies. However, very few Asian Elephant populations have been studied (Sukumar 1991; Katugaha *et al.* 1999). Population estimates using scientific repeatable methods are rare and therefore their usefulness across the elephant range in Asia to assess viability is limited. In addition to data on demographic parameters (i.e. age-sex structure, estimates of inter-calving period, age at first conception, mortality rates) population estimates are very important to assess the status and viability of a population, yet such data is non-existent for the majority of Asian Elephant populations.

The Asian Elephant in India (*c.* 17,000-22,000) occurs in 5 major disjointed populations (Sukumar 1991; Daniel 1998). In north-west India, an estimated 800-1,000 elephants occur in Rajaji National Park (RNP), Corbett Tiger Reserve (CTR) and the adjoining forest areas. This range has been designated as Elephant Reserve 11 by the Government of India (Anon. 1993). However, the area is fragmented into 3 sub-populations (Johnsingh and Joshua 1994) and genetic continuity between them is probably maintained only by a few adult males that migrate through narrow and highly disturbed corridors.

One of the sub-populations lies between the Ganga and Yamuna rivers (Johnsingh and Joshua 1994). Elephants in this area stopped crossing the Ganga river due to the construction of a 14 km long power channel on the eastern bank (Singh 1978) and loss of a portion of the corridor area to resettlement programmes for villagers displaced by the construction of a dam upstream. In addition to the power channel, a state highway and a railroad in a corridor area prevented female movement across the Ganga river. Today potential genetic continuity between populations on either bank of the Ganga river is due to 3 or 4 bulls crossing through a narrow corridor (A.C. Williams, Unpublished data).

Information on how many elephants were present on the west bank of the Ganga river prior to and after the construction of the power canal in early 1970s is not available.

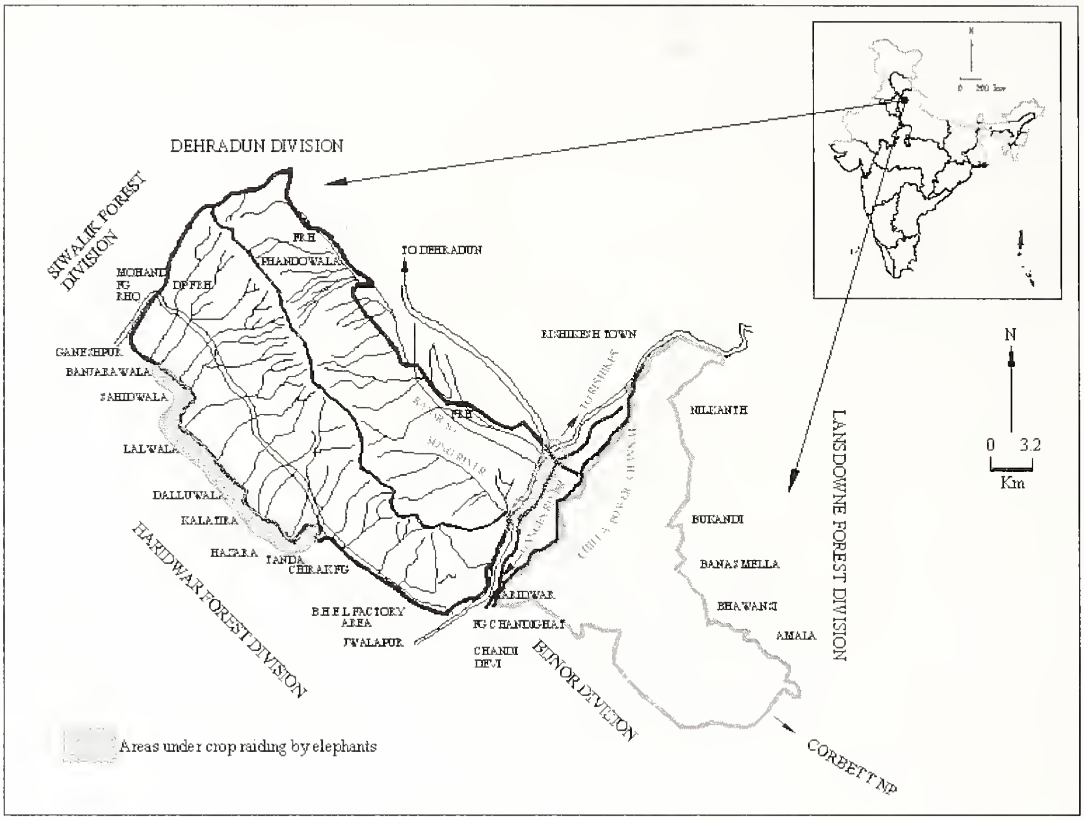

Fig. 1: Map of Rajaji National Park

Singh (1995) reported a population of 180 elephants between the Yamuna and Ganga rivers. Though ecological research on elephants in this area began in 1986, no detailed study on the elephant demography in this tract was done. As a result effective management plans could not be developed with elephant conservation as the focal point. At the same time elephants were being killed in elephant-human conflict and the effect of these losses could not be predicted, due to lack of data. Therefore, we conducted a study on elephant demography in the areas to the west of the Ganga river between 1996 and 1999. Our objectives were to investigate population parameters, like age-sex structure, inter-calving period, and calf and adult survival, and to use population models to predict the viability of this elephant population.

STUDY AREA

This study was conducted in RNP west of the Ganga river (Fig. 1) between January 1996 and June 1999. The area includes the Rajaji and Motichur sanctuaries and portions of the Shivalik and Dehradun east Forest Divisions covering an area of *c*. 500 sq. km. The distinct spine of the Shivalik ridge forms a natural boundary between Rajaji and Motichur sanctuaries. Terrain in the Rajaji Sanctuary consists of deeply dissected steep southern slopes of the Shivalik hill range, which form a series of sharp ridges, interspersed with V-shaped valleys running from north-east to south-west. The southern portion of the Sanctuary is a flat land constituting the northern fringe of the Gangetic plain (J.B. Sale, Wildlife Institute of India, unpublished report 1987). The altitude ranges from 400 to 1,000 m above sea level. Rajaji Sanctuary is divided into hills and plains. Over 1,40,000 people live along the periphery (D. Kumar, Wildlife Institute of India, unpublished report 1998). Their main source of livelihood is agriculture. The study area is bounded by intense cultivation to the north and south, and by the suburbs of the town Haridwar, on the bank of the Ganga River, to the east; to the west the Delhi-Dehradun highway separates the RNP from the Shivalik Forest Division.

Rainfall ranged from 1,300 to 1,900 mm during 1996-1999 with most of the rain falling during July to October. However, there are brief periods of rainfall throughout the year. Three distinct seasons are recognized: winter (November to March), summer (March to July) and monsoon (July to November). The major vegetation associations in this area are tropical dry deciduous dominated by *Shorea robusta*, tropical mixed forest containing *Shorea robusta*, *Mallotus philippinensis*, and *Ehretia laevis*, miscellaneous forests with *Zizyphus xylopyrus*, *Helicteres isora*, *Anoegesis latifolia*, *Dendrocalamus strictus* and plantations with *Dalbergia* *sisoo*, *Acacia catechu*, *Garuga pinnata* and *Aeilanthus excelsa*. In addition to elephants, the study area provides habitat for other large mammals including Sambar (*Cervus unicolor*), Chital (*Axis axis*), Muntjac (*Muntiacus muntjak*), Nilgai (*Boselaphus tragocamelus*), Goral (*Nemorhaedus goral*), Wild Pig (*Sus scrofa*), Tiger (*Panthera tigris*), and Leopard (*Panthera pardus*). There are more than 4,000 nomadic pastoralists (i.e., Gujjars) and about 8,300 of their livestock within the study area. These Gujjar families live scattered all over the study area in small colonies. Recently, there has been a resettlement programme under which the Gujjar families are being moved away from the Park into more permanent settlements. Therefore, the biotic pressure exerted by the Gujjars is decreasing within the Park. The majority of the people in and out of RNP depend on the forests in the study area to meet their fuel wood and forage requirements.

METHODS

We immobilized four male and four female elephants with Immobilon (a mixture of Etrophine hydrochloride and Acepromazine), delivered with a dart gun, and fitted them with radio transmitters embedded on an acrylic collar (Telonics Inc., Arizona, USA). Three males and four females were radio-tracked for 1 to 2 years. We used the Mark Re-sight method (White 1996) between January 1997 and June 1998 to estimate the size of the adult male population. We identified 10 adult male elephants using distinctive naturally occurring marks (e.g. tusk shape and length, and cuts, notches and degree of ear folding) and used them with 3 adult males fitted with radio-transmitters as the marked sample. Females were difficult to identify as they did not possess tusks and it was difficult to approach them undetected close enough to be able to use other physical characteristics with any degree of success. Since no female groups encountered could be identified with certainty either as marked or unmarked, we chose to estimate only the male population size using the Mark Re-sight method. Forest blocks chosen randomly were searched for 211 days from January 15, 1997 to June 1, 1998 for 2 to 4 hours. All elephants (adult males and female groups) encountered were recorded and if marked, their identity was noted. The radio-transmitter frequencies were used only to confirm the identity of the individual male. We used the Bowden's estimator (Bowden and Kufeld 1995) to estimate the number of adult males in the population. These authors came up with a modified estimator of the Minta-Mangel model (Minta and Mangel 1989) where the variance on the re-sighting frequencies of marked animals was used for computing the confidence interval. Each animal in a population has a sighting frequency f_i. The values of f_i for marked samples are known and the sum of f_i for the unmarked animals is also known when the mark re-sighting sampling is done. Using this as an unbiased estimator and its variance were suggested (see Bowden and Kufeld 1995 for more details). The advantage of the Bowden estimator is that it allows for heterogeneity in capture probabilities and for sampling with or without replacement. The calculations were done using the Programme NOREMARK (White 1996).

We collected data on age-sex structure of the elephant population from March 1996 to June 1998. We encountered elephants when we were either searching randomly chosen forest blocks or while radio-tracking collared elephants. Whenever a female group was encountered, we classified the elephants into various age-sex categories based on relative height and morphological characteristics (McKay 1973; Kurt 1974; Daniel *et al.* 1987). Younger elephants (<15 years) were classified by comparing their height to the oldest adult female in the group (Eisenberg and Lockhart 1972). Elephants were placed in broad age groups; calves (<1 year old), juveniles (1-5 years old), subadults (5-15 years) and adults (>15 years). We included radio collared elephants in the classification data only if they were encountered randomly while searching for other elephants, not when they were located with the help of a radio signal.

We classified all adult males. However, female groups were larger and more difficult to classify than males that were usually solitary in a forested habitat like RNP. A female group was considered fully classified when all the members, except calves (<1 year old), were assigned to specific age-sex classes. Computing sex ratios using only the fully classified groups led to under-estimation of the other age-sex class proportions in the population. To correct this under-estimation, we applied the age-sex ratios of the fully classified groups to those unclassified groups in which all the elephants were counted. For those groups that were not fully counted we applied the average group size and age-sex ratios of the fully classified groups. The above correction would be wrong if unclassified groups were smaller or larger than the fully classified groups. Hence, we tested for differences in mean group sizes and distribution of group sizes between fully classified and unclassified groups. Thus, we had calculated proportions of the various age-sex classes (adult male, adult female, subadult male, subadult female, juveniles and calves) out of the total animals classified. Since we had also estimated the number of adult males in the population using mark re-sight, we estimated the numbers of the other age-sex classes by computing their proportions relative to the adult male segment and using the following simple calculation;

No. of elephants in a particular age-sex class = $(P_{iM} / P_{AS}) / N_m$

Where P_{iM} = Percentage of males in total elephants age-sex classified, P_{AS} = Percentage of elephants in a particular age-sex class, in total elephants age-sex classified, for which we are estimating numbers, N_m = No. of males estimated by the Mark Re-sight method.

To estimate inter-calving period and calf survival, we followed 19 identified females in the four collared groups and recorded the number of calves born and their survival for 3 years until May 1999. We recorded all the elephant deaths in the study area and classified them as either natural mortality or mortality related to human influence.

We used Kruskal-Wallis (K-W) One Way Analysis of Variance (ANOVA) when testing for differences in group sizes between 3 years and 3 seasons. We used Mann-Whitney (M-W) U for testing between years and seasons. We used Kolmogorov-Smirnov (K-S) two-sample test when testing for differences in the distribution of group sizes between years and seasons.

RESULTS

We recorded 101 sightings of adult males with 42 re-sightings (Table 1) of 13 marked males. All the marked animals were re-sighted during the sampling period and there was heterogeneity in sighting probabilities (Table 1). The number of adult males in the study area was estimated to be 31 (95% CI = 23-41 adult males). Males formed 16.5% of the total elephants classified (Table 2). The estimates for the other age-sex classes were computed from their relative proportions to the male segment (Table 3). There were 3 tuskless adult bulls in the population of 31 adult males indicating that >90% of the males are tuskers. We estimated a population of 188 elephants (95% CI = 139-248) in Rajaji National Park and adjoining forest areas to the west of the Ganga river (Table 3). We found the adult male to female sex ratio was 1: 1.87. This gives a crude density of 0.33 elephants/sq. km.

Between March 1996 and June 1998, we encountered males on 121 occasions and female groups on 91 occasions. Forty five percent of the female groups encountered (n = 91) were fully classified and in another 31% of the encounters, a count of all the group members was made, but they were not classified into the various age-sex categories. We found no difference (Mann-Whitney U, z = -1.0562, P = 0.29) in the mean group size or in the distribution of group sizes (K-S test, z = 0.750, P = 0.627) between fully classified groups (X = 7.20, n = 41) and unclassified groups (X = 6.64, n = 28). This indicated that size of the group did not influence whether a group was classified or not. We also did not find differences in mean group sizes (Table 1, K-W ANOVA, X^2 = 3.516, P = 0.17) or in age-class structure of the female groups (X^2 = 1.5067, P = 0.99) between years. Elephants formed smaller groups in rainy season (Table 4), but we could not detect a difference in the mean group size between the seasons (K-W ANOVA, X^2 = 3.472, P = 0.17).

We classified 300 elephants encountered in 41 female groups and 125 elephants in 121 male groups into age-sex classes. Most of the adult male sightings (>80%) were solitary. We applied the proportions estimated from the fully classified groups to the unclassified female groups to correct for under representation of the female, juvenile and subadult segment of the population (Table 2). The juvenile sex ratio was almost

Table 1: Sighting frequencies of 13 identified male elephants in Rajaji National Park, India and adjoining forest areas, 1997-1998

No. times sighted	1	2	3	4	5	6	7	8	9
Number of elephants	2	4	2	3	1	0	0	0	1

Table 2: The age-sex structure of elephants classified (N=756) in Rajaji National Park, India 1996-1999

Age-class	Percentage	
	Males	Females
Adults	16.5	30.9
Subadults	14.4	8.0
Juveniles	8.8	8.7
Calves	12.8	

Table 3: Estimate of the number of elephants in Rajaji National Park, India the various age-sex classes computed from their relative proportions to the adult male age class and associated confidence intervals (CI)

	Mean	95% lower CI	95% upper CI
Adult male	31	23	41
Adult female	58	43	77
Subadult male	27	20	36
Subadult female	15	11	19
Juvenile male	16	13	22
Juvenile female	17	12	21
Calves	24	18	31
Total	188	139	248

Table 4: The mean group size and standard error (SE) of the female groups in the three seasons in Rajaji National Park, 1996-1999

Season	N	Mean	SE
Summer	32	7.78	0.79
Rainy	20	5.50	0.69
Winter	17	7.18	1.30

equal among the juveniles that were classified by sex (n = 61). Forty one percent of the adult females were accompanied by a calf and >92% of the adult females had at least one young (<5years old) at heel. There were more subadult males than subadult females in the population (Table 2).

The 19 identified adult females in the four collared groups gave birth to 13 calves between 1996 and 1999. In the third year, one of the adult females and her calf were killed and another female could not be traced. All the females gave birth to their calves at the end of monsoon season. The number of calves born to the 19 identified females between 1996 and 1999, and surviving at the end of the first year is given in Table 5. The total adult female years monitored was 55 years and we calculated an inter-calving period of 4.23 years. All calves (n = 5) born during 1996-1997 survived for >2 years, and all but one of the calves (n = 7) born during 1997-1998 have survived for more than 1 year and 8 months.

Elephants died due to natural causes including old age and disease, and due to human related causes including train accidents, electrocution, and being killed while crop raiding. We found that twice as many elephants were killed due to human related causes as from natural causes (Table 6). Trains were responsible for more than 88% of the females and young killed (n = 9). Proportionately more adult males (3.87 males/100 males/year) died than adult females (1.72 females/100 females/year). This also held true when only adult elephants killed due to human related causes were considered; more adult males (1.94 males/100 males/year) were killed than adult females (1.23 females/100 females/year). Two female elephants and one male elephant were killed during attempted crop raiding while another adult male was almost electrocuted in the process of crop raiding.

DISCUSSION

All the males encountered were classified, as more than 95% of the sightings were of solitary males and thus close approach was possible to classify the individual. Females live in social groupings comprising of related females and their young (Douglas-Hamilton 1972) and were less tolerant of the presence of humans and hence they were difficult to approach and classify in the thick vegetation. Our results indicate that the size of the group did not influence whether a group was classified or not and also that group sizes did not differ between years or seasons. Therefore our decision to apply the age-sex structure and the average group size to unclassified groups to correct for under-representation of the female and associated age-sex classes was justified. Except for studies conducted in fairly open habitats (Katugaha 1999; de Silva *et al.* 1995), most Asian Elephant habitats are similar in structure to our study site.

The female elephants in our study area lived in social groupings of one or more adult females and their offspring as reported from Africa and Asia (Moss and Poole 1983; Moss 1988; de Silva *et al.* 1995). The females also formed similar sized groups to those reported from other studies (range 5.5 to 13.9) in Asia (Eisenberg and Lockhart 1972; McKay 1973; Kurt 1974; Daniel *et al.* 1987; de Silva *et al.* 1995). Mean group size varied between the monsoon season and the other seasons (Table 4). Mean group size can be expected to decrease when the forage is scarce and poor in quality. However, in the rainy season the quality of the forage is high. A favoured monsoon season forage species like *Dendrocalamus strictus* is distributed patchily, and smaller groups of elephants may be better able to utilize such a resource than a large group. Such a pattern has been reported for forest elephants in Africa where fruit resources are distributed patchily (White *et al.* 1993). Few adult males were seen with female groups outside of their musth period. Adult males were usually solitary as reported from other areas in Asia (Santiapillai *et al.* 1984; Daniel *et al.* 1987; Katugaha *et al.* 1999) and in Africa (Croze 1974; Poole and Moss 1981).

Adult dominated age-structures are common in Asian Elephant populations (Eisenberg and Lockhart 1972; Chandran 1990; Katugaha *et al.* 1999) given their long life span and slow reproductive rate. However, we found that there were more subadult and young elephants in the population than

Table 5: Annual birth rate of the elephant population in Rajaji National Park, India 1996-1999

	1996-97	1997-98	1998-99
Number of identified adult females	19	19	17
Number of calves born	5	7	1
Birth rate (No. of calves/adult female)	0.26	0.37	0.06

Table 6: Number of elephant deaths due to natural and human related causes in the study area, 1992-1999[a]

	No. found dead due to	
	Natural causes	Human related
Adult male	3	3
Adult female	2	5
Subadult male	-	1
Subadult female	-	2
Juvenile male	1	-
Juvenile female	-	1
Calves	-	2
Total	6	14

[a] - Deaths of adult and subadult males recorded only from 1994

adult elephants, which was similar to two other studies in southern India (Daniel *et al.* 1987; Sukumar 1991). Age structure of a population can lean towards the younger age classes due to improved fertility rates and calf survival (Caughley 1974), or due to higher mortality of adults (Jachmann 1986; Ottichilo 1986). Because there has been no report of increased mortality of adults in the study area, we think that improved fertility and calf survival is a major factor for the age structure being in favour of younger age-classes.

In contrast to other studies on elephants on mainland India (Daniel *et al.* 1987; Chandran 1990; Sukumar 1991), there were more subadult males than females in this population. In the other studies, poaching played an important role in reducing the proportion of males (subadult and adult). We did not record a single incident of poaching in the study area, but this does not explain why there is a male biased sex ratio at the subadult level. We found an almost equal sex ratio among the juveniles between 3-5 years old. The percentage of young (<5 years old) observed in this study was within the range reported for Asian Elephants in India (Daniel *et al.* 1987; Chandran 1990; Sukumar 1991).

The adult sex ratio was the least skewed among the populations studied, so far, in India. In fact the adult sex ratios were comparable to those reported from Sri Lanka (1 male: 1.9 females) where >90% of the males are tuskless (Katugaha *et al.* 1999) and hence poaching is not a problem. The north-west Indian population is the only Asian Elephant population in India where the adult sex ratio is comparable to those of the Sri Lankan populations. The proportion of adult males (16.5%) in the population is the highest when compared to other studies in mainland India (Daniel *et al.* 1987; Chandran 1990; Sukumar 1991). The reason for this is the lack of poaching in the study area during the study period.

We used the Mark-Resight method for the first time in Asia to estimate elephant numbers. We had a very high re-sighting percentage of males. However, there was a wide variation between the identified males in the number of times they were re-sighted (Table 1). We think one of the reasons for this is that some males in the study area have home ranges twice as large as other males, and thus could have been sighted by chance more often. This was the first study on Asian Elephants where numbers of males or estimates of any other age-sex class have been presented with a 95% confidence interval and therefore direct comparisons cannot be made to other studies. The estimate of 180 elephants reported by Singh (1995) was within the 95% confidence interval of 139-248 elephants estimated by us, indicating concurrence with estimates by another method. The proportion of males having tusks was similar to those of the populations studied in southern India (Daniel *et al.* 1987; Sukumar 1991). The effective population size of 80+ is higher than the minimum of 50 recommended (Franklin 1980; Frankel and Soule 1981) for the population to be safe purely from environmental and demographic stochasticity in the short term (100 years). Though this thumb rule has been criticized, Boyce's (1992) review of data showed that these are safe estimates for large mammals.

In certain populations (Chandran 1990) lack of adult males due to poaching has caused a drop in calving rates because of inability of females to find a male. We found that >95% of the adult females in our study had one young <5 years old at heel, indicating that most females do not have problems finding mates. There is a birth peak in most of the populations studied (Ishwaran 1981; Sukumar 1991; Katugaha 1993) even though newborn calves are seen throughout the year. We found that females gave birth mainly after the peak monsoon season. During the entire study period only one newborn calf was observed outside September-October. Cows need extra nutrition to support lactation (Barnes 1983; de Silva *et al.* 1995) and they also need to be in the best body condition. There is abundance of high quality food, especially new flush grass, immediately after peak monsoon season and this also coincides with the peak calving period. In the first two years of the study elephant births were high (Table 5). We calculated an inter-calving period of 4.23 years, which was similar to the inter-calving period calculated from two other studies in India (Daniel *et al.* 1987; Sukumar 1991). However, if 90% of the remaining six identified females give birth in the following year (1998-99), the inter-calving period would be around 4 years, the lowest recorded for Asian Elephants. We believe this is possible because the inter-calving period recorded from the birth of one calf to another for an identified female tracked in an area adjacent to our study site was 3.1 years (J. Joshua, Wildlife Institute of India, Unpublished Report 1993). This was the shortest recorded for elephants (Asian and African) (Laws *et al.* 1975; Smuts 1977; Jachmann 1986) indicating that elephants in RNP are experiencing a phase of high fecundity.

Earlier there were only estimates of calf survival and mortality was assumed to be around 10-25% (Daniel *et al.* 1987; Sukumar 1991). Ours was the first study which followed 12 identified female-calf units for over a year to estimate calf survival and we found that it was >90%. The only calf which died was involved in a collision with a train, which is not natural mortality. In the future the age-structure is going to be dominated by younger age classes. However, the age-ratios need to be interpreted cautiously (Caughley 1974; McCullough 1994) as the study population is undergoing an increased rate of mortality of adult females due to human induced causes.

More elephants died due to human induced causes than natural mortality. The chance of an adult male dying was higher than that of adult females, even when only deaths due to human induced causes were considered. In recent years, there have been losses of whole family groups or part of groups in train accidents. Sometimes the matriarch gets killed in these accidents. The matriarchs play an important role in elephant society and are repositories of traditional knowledge, knowing where to go during times of drought (which may occur once in 20-25 years) in search of food and water (Moss 1988). The younger females may not have this knowledge, as they might not have experienced a drought since they were born, and the effects of such losses are yet to be quantified.

Barnes and Kapela (1991) showed that the Ruaha elephant population had very poor recruitment when the adults were being poached at a high rate, illustrating that loss of adult females had an impact on every aspect of the population biology. Simulations have shown elephant populations to decline even with adult mortality rates as low as 1.5-5% if the fertility rates went down (Hanks and McIntosh 1973). Females may stop conceiving if a large number of females were to be killed every year, as happened in Ruaha (Barnes and Kapela 1991). Even if accidents were stopped, habitat degradation, which is a major problem, might affect the population parameters, thus increasing the probability of extinction (Armbuster and Russell 1993). The high proportion of males in the population, low inter-calving period and high neonate survival of the population in RNP point to a demographically healthy population. The age-structure and population parameters compare very favourably with African elephant populations known to be increasing (Douglas-Hamilton 1972; Smuts 1977). However, it would only take the death of a few more adult females/year to seriously threaten the population viability, as it is a small population. We must take urgent steps to minimize the loss of adult females to accidents and stop habitat degradation in order to keep this small elephant population viable.

CONCLUSION

The Rajaji elephant population is demographically healthy from the population characteristics (sex ratios, age-structure, inter-calving period and calf survival). However, the occasional crossing of a few elephant bulls between Motichur and Chilla across Ganga river needs to be maintained to ensure the chance of genetic flow between the otherwise fragmented populations. This will be crucial to ensure that effective population size above the critical minimum is maintained. However, too many elephants are being lost to train accidents in the study area. An analysis of future population trends, using mathematical models, indicates that a slight rise in the number of females getting killed would significantly increase the chances of this population going extinct in 100-200 years (A.C. Williams, unpubl. data). Poaching was not a problem in the study area, but a few cases were seen suddenly in 2001, and this is a cause for worry as it exposed the inadequacy of protection resources. It is urgent for the Government to take steps to reduce elephant deaths due to train accidents and poaching to ensure that this small population survives.

ACKNOWLEDGEMENTS

We thank the Officers of the Uttarakhand Forest Department, the Additional Inspector General of Forests (Wildlife), Ministry of Environment and Forests, Government of India and Director, Project Elephant, Government of India who granted the permissions for this study. We wish to thank the faculty and staff at the Wildlife Institute of India and the University of Arizona who helped us during analysis and writing of the first authors' PhD thesis, which led to this manuscript. The United States Fish and Wildlife Service funded this project and we particularly thank Dave Ferguson and Fred Bagley for all the encouragement and support rendered to carry out this research.

REFERENCES

ANON. (1993): Project Elephant (*Gajatme*). Ministry of Environment and Forests, Government of India, New Delhi.

ARMBUSTER, P. & R. RUSSELL (1993): A population viability analysis for African elephant (*Loxodonta africana*): How big should reserves be? *Conservation Biol. 7(3)*: 602-610.

BARNES, R.F.W. (1983): Elephant behaviour in a semi-arid environment. *Af. J. Ecol. 21*: 185-196.

BARNES, R.F.W. & E.B. KAPELA (1991): Changes in the Ruaha elephant population caused by poaching. *Afr. J. Ecol. 29*: 289-294.

BOWDEN, C.D. & R.C. KUFELD (1995): Generalized mark-sight population size estimation applied to Colorado moose. *J. Wildl. Manage. 59(4)*: 840-851.

BOYCE, M.S. (1992): Population viability analysis. *Ann.l Rev. Ecol. Sys. 23*: 481-506.

CAUGHLEY, G. (1974): Interpretation of age ratios. *J. Wildl. Manage. 38(3)*: 557-562.

CHANDRAN, P. (1990): Population dynamics of elephants in Periyar tiger reserve. Pp. 51-55. *In*: (Ed: Karunakaran, C.K.) Proceedings of the symposium on ecology, behaviour and management of elephants in Kerala. Wildlife Wing, Kerala Forest Department Thiruvananthapuram.

CROZE, H. (1974): The Seronera bull problem – The Elephants. *E. Afr. Wildl. J. 12*: 1-27.

DANIEL, J.C. (1998): Elephant at crossroads. Pp. 1-2. *In*: (Ed: Anon.)ENVIS (Wildlife and Protected areas). Wildlife Institute of India, Dehradun.

DANIEL, J.C., A.A. DESAI, N. SIVAGANESAN & S.R. KUMAR (1987): The study of some endangered species of wildlife and their habitats - The Asian Elephant. Report: October 1985 to September 1987. Bombay Natural History Society, Bombay.

DE SILVA, M., B.V.R. JAYARATNE & P.K. DE SILVA (1995): The status and other ecological aspects of the elephant population in Ruhuna National Park, Sri Lanka. *J. South Asian nat. Hist. 1(2)*: 185-202.

DOUGLAS-HAMILTON, I. (1972): On the ecology and behaviour of the African elephant. D. Phil. thesis, University of Oxford. 268 pp.

EISENBERG, J.F. & M. LOCKHART (1972): An ecological reconnaissance of Wilapattu National Park, Ceylon. Smithsonian Contribution to Zoology. Vol. 101. Smithsonian Institution, Washington, DC. 118 pp.

FRANKEL, O.H. & M.E. SOULE (1981): Conservation and Evolution. Cambridge University Press, Cambridge. 327 pp.

FRANKLIN, I.R. (1980): Evolutionary change in small populations. Pp. 135. *In*: (Ed: Soule, M.E. & B.A. Wilcox) Conservation Biology: an Evolutionary-Ecological Perspective. Sinauer Associations, Sunderland, MA.

HANKS, J. & J.E.A. MCINTOSH (1973): Population dynamics of the African elephant (*Loxodonta africana*). *J. Zool. 169*: 29-38.

ISHWARAN, N. (1981): Comparative study on elephant populations in Gal Oya, Sri Lanka. *Biol. Cons. 26*: 255-270.

JACHMANN, H. (1986): Notes on the population dynamics of the Kasungu elephants. *Afr. J. Ecol. 24*: 215-226.

JOHNSINGH, A.J.T. & J. JOSHUA (1994): Conserving Rajaji and Corbett National Parks – the elephant as a flagship species. *Oryx 28*: 135-140.

KATUGAHA, H.I.E., M. DE SILVA & C. SANTIAPILLAI (1999): A long-term study on the dynamics of the elephant (*Elephas maximus*) population in Ruhuna National Park, Sri Lanka. *Biol. Cons. 89*: 51-59.

KEMF, E. & C. SANTIAPILLAI (2000): Wanted Alive! Asian Elephants in the Wild. A 2000 WWF Species Status Report. WWF-International. Gland, Switzerland. 32 pp.

KURT, F. (1974): Remarks on the social structure and ecology of the Ceylon elephant in Yala National Park. Pp. 618-634. *In*: (Eds: Geist, V. & F. Walther) The behavior of ungulates and its relation to management. IUCN, Morges, Switzerland.

LAWS, R.M., I.S.C. PARKER & R.C.B. JOHNSTONE. (1975): Elephants and their habitats: the ecology of elephants in north Bunyoro, Uganda. Oxford University Press, London.

LEUTHOLD, W. (1976): Group size in elephants and possible factors influencing it. *J. Anim. Ecol. 45*: 425-439.

MCCULLOUGH, D.R. (1994): What do herd composition counts tell us? *Wildl. Soc. Bull. 22*: 295-300.

MCKAY, G.M. (1973): Behavior and ecology of the Asiatic elephant in southeastern Ceylon. Smithsonian Contribution to Zoology. Vol. 125. Smithsonian Institution, Washington, DC.

MINTA, S. & M. MANGEL (1989): A simple population estimate based on simulation for capture-recapture and capture-resight data. *Ecol. 70*: 1738-1751.

MOSS, C.J. (1988): Elephant Memories: Thirteen Years in the Life of an Elephant Family. Chicago University Press, Chicago. 336 pp.

MOSS, C.J. & J.H. POOLE (1983): Relationships and social structure of African elephants (Section 13.4). Pp. 315-325. *In*: (Ed: Hinde, R.A.) Primate social relations: an integrated approach. Blackwell Scientific Publications, Oxford.

OTTICHILO, W.K. (1986): Age structure of elephants in Tsavo National Park, Kenya. *Afr. J. Ecol 24*: 69-75.

POOLE, J.H. & C.J. MOSS (1981): Musth in the African elephant, *Loxodonta africana*. *Nature. 292(5826)*: 830-831.

SANTIAPILLAI, C., M.R CHAMBERS & N. ISHWARAN (1984): Aspects of the ecology of the Asian elephant (*Elephas maximus*) in the Ruhuna National Park, Sri Lanka. *Biol. Cons. 29*: 47-61.

SINGH, K.N. (1995): Asiatic elephants in Uttar Pradesh (India). Status and strategy for conservation. Pp. 32-48. *In*: (Eds: Daniel, J.C. & H.S. Datye) A Week with Elephants. Bombay Natural History Society, Oxford University Press, Bombay.

SINGH, V.B. (1978): The elephant in U.P. (India) – A resurvey of its status after 10 years. *J. Bombay Nat. Hist. Soc. 75*: 71-82.

SMUTS, G.L. (1977): Reproduction and population characteristics of elephants in Kruger National Park. *J. Southern. African Wildlife Management Association 5*: 1-10.

SUKUMAR, R. (1991): The Asian Elephant: Ecology and Management. Cambridge University Press, Cambridge, United Kingdom. 273 pp.

WHITE, G.C. (1996): NOREMARK: Population estimation from mark-resighting surveys. *Wildl. Soc. Bull. 24*: 50-52.

WHITE, L.J.T., C.E.G. TUTIN & M. FERNANDEZ (1993): Group composition and diet of forest elephants, *Loxodonta africana cyclotis* Matschie 1900, in the Lopé Reserve, Gabon. *Afr. J. Ecol. 31(3)*: 181-199.

■ ■ ■